

# **Vadose Zone Transport Field Study Project**

## **Broad Test Plan Rev 1.0**

(1/19/2000)

### **1.0 INTRODUCTION**

Vadose zone is a geologic term used to define that portion of the earth's crust that lies between land surface and the underlying water table. At the Hanford Site, the thickness of the vadose zone varies from a few meters near the Columbia River to more than 100 m (<300 feet) near waste sites located on the 200 Areas Plateau, some 20 to 30 km from the river. At Hanford, radioactive and hazardous wastes have been stored in the vadose zone since the 1940s. At some locations, contaminants have moved downward through the vadose zone and over time have contributed to groundwater contamination. Quantification of actual amounts and locations of the contributing contaminant plumes within the vadose zone, however, has been illusive in spite of more than 1300 monitoring wells and over 40 years of characterization efforts. For example, recently discovered high levels of technetium-99 in groundwater wells near the SX tank farm have been attributed to tank leaks, yet extensive downwell monitoring has not identified the extent of the technetium plume in the SX vadose zone. These and similar observations at other waste sites have raised increasing concerns about the adequacy of vadose zone monitoring and the ability of computer models to predict timing and extent of contaminant migration to the water table and expected future groundwater contamination levels.

Recent characterization efforts in the tank farms have relied on core sampling techniques. Analysis of cores taken from the depth of the leak to below the water table have been useful in identifying localized zones of contamination. Unfortunately, these analyses are sparse and extremely expensive. Without more coring it will be difficult to clearly identify the extent of the contamination plume at a given location in the heterogeneous vadose zone at Hanford waste sites. However, the dilemma is cost, time, and practicality of such a characterization effort. In the past, the cost of drilling and core analysis has exceeded \$1M per borehole for the sampling in the T and SX tank farms. While some of these costs may be reduced in the future it also takes months to complete the analysis, when answers are needed today. It is apparent that improved characterization and modeling methods are desperately needed that can reduce costs and shorten the time for analysis and provide reliable estimates of vadose zone contaminant plumes at the Hanford Site.

The focus of the Vadose Zone Transport Field Study effort is to evaluate improved or advanced characterization methods that can be applied quickly and cost effectively through a series of field tests. Both cost and time reduction are important elements of the evaluation process. In addition, these tests will be designed to clearly delineate plume migration under Hanford site conditions. The data obtained from these tests will then be used to develop improved conceptual models and numerical codes for prediction of contaminant transport in the vadose zone at Hanford.

Mathematical models of contaminant transport through the vadose zone are important tools in the assessment of risk of contamination and for the development of remediation technologies.

Essential prerequisites for successful application of mathematical models include accurate conceptual models as well as constitutive properties derived from observations of flow and transport through the medium of interest.

Prediction of unsaturated transport requires an understanding of the flow of multiphase (air, water, organics) and multicomponent (contaminants, microbes, colloids) fluids through variably saturated soils. There is a need for information on heterogeneities, as these features can alter contaminant transport significantly. In addition, the influence of heterogeneities on transport can vary depending on the initial and boundary conditions. At Hanford, heterogeneities of interest can range from localized phenomena such as silt or gravel lenses, fractures, clastic dikes, to large-scale lithologic discontinuities. These features have been suspected of leading to funneling and fingering, additional physical mechanisms that could alter and possibly accelerate the transport of contaminants to underlying groundwater.

Considerable information has been obtained about the physics of variably saturated flow and transport and the corresponding parameters via laboratory experiments and pore-scale models. However, even over relatively short distances, there are heterogeneities in the physical structure of the porous medium and structural differences between repacked soil cores and the field site from which the materials initially came. Such complications make it difficult to use laboratory data to predict field performance. Many of the parameters required for simulations are also collected at a scale different from (usually smaller than) the one used to discretize the porous medium in the numerical model. For example, saturated hydraulic conductivity ( $K_{\text{sat}}$ ) and matric potential-water content relationship ( $\psi[\theta]$ ) are often determined from core measurements with measurement supports on the order of centimeters to meters, while numerical models often require measurements representative of tens to hundreds of meters. Because the length scales of the resulting data are quite different from those required for field-scale interpretations and predictions, it is important that studies aimed at unraveling the effects of the physical basis of nonequilibrium flow be conducted at the appropriate scale.

A number of large-scale transport studies conducted during the last decade have identified important features in vadose zone flow and transport processes. While these studies have yielded useful information, none have been conducted at the Hanford Site and the results have often proven to be specific to the particular site and to the experimental conditions. Site specificity is due to very few studies attempting to correlate the observed flow and transport phenomena with the site's hydraulic properties. Consequently, extrapolation of existing information to different soil textural classes at a specific site; to larger spatial and temporal scales at the same site; to different experimental/boundary conditions; or to different sites, is problematic. At Hanford, this increases the difficulty in interpreting existing contaminant plumes and predicting future migration using existing conceptual models and results extrapolated from observations at other DOE Sites.

## **2.0 PURPOSE AND SCOPE**

The purpose of the Vadose Zone Transport Field Study (VZTFS) Project is to provide data needed to improve conceptual models and calibrate numerical models for variably saturated water

flow and contaminant transport through the heterogeneous sediments of the Hanford vadose zone using improved, cost effective characterization methods. The project proposes a number of field experiments to be conducted under controlled conditions at one or more clean sites. The project has identified a number of FY2000 Environmental Management and Science Program (EMSP) research awards (see Table 1) that will complement the work planned for the test sites at Hanford, and in so doing, provide more meaningful results.

There is a clear need for characterization techniques that provide more cost effective and timely analysis of contaminant plumes at tank farms and other waste sites at Hanford. Methods that can capture the extent of the plume using existing infrastructure (i.e., over 1300 vadose zone wells) will receive high priority. Advanced characterization methods that have not yet been deployed at Hanford will be evaluated through a workshop devoted to the evaluation of commercially available vadose zone techniques. Interaction with EMSP investigators in the development and testing of advanced methods will also be key to improving Hanford Site vadose zone monitoring.

Although developing an understanding of contaminant transport associated with tank leaks and other vadose zone plumes found at Hanford will require investigations of multiphase and multicomponent fluid flow, the initial emphasis will be on evaluating movement of the aqueous phase. Key geohydrologic and chemical processes controlling contaminant migration, particularly those suspected of contributing to non-uniform or accelerated transport, will be evaluated in the first four years. In subsequent years, microbial processes will be considered. Controlled experiments will be conducted at radiologically “clean” sites representative of WMAs, such as tank farms and specific retention cribs. Representative sites will be selected to meet certain physical and geohydrological criteria while minimizing the risk to investigators and providing easy site access to conduct meaningful field investigations.

**Table 1.** Summary of FY 2000 EMSP Awards With Potential for Incorporation into the Vadose Zone Field Study

<b>Institution</b>	<b>Investigator</b>	<b>\$ Award</b>	<b>Title</b>	<b>Summary</b>
LBNL	Dr. T. K. Tokunaga	450,000	Fast Flow in Unsaturated Coarse Sediments	To improve our understanding of unsaturated flow in coarse- to very coarse-textured sediments. Through development of new conceptual models and laboratory experiments on fast flow processes, results will help to predict contaminant transport in vadose environments.
LLNL	Dr. P. A. Berge	750,000	Effects of Fluid Distribution on Measured Geophysical Properties for Partially Saturated, Shallow Subsurface Conditions	To measure properties of partially saturated samples and to improve the interpretation of geophysical field measurements used to characterize the subsurface and monitor remediation in the vadose zone. The results will help delineate and verify removal of DNAPLs and improve understanding of contaminant transport in a fractured rock vadose zone.
LLNL	Dr. C. R. Carrigan	600,000	The Dynamics of Vadose Zone Transport: A Field and Modeling Study Using the Vadose Zone Observatory	To characterize vadose zone fluid flow and contaminant transport processes for the purposes of making improved estimates of contaminant release rates and fluxes across the vadose zone to the water table at DOE Sites
University of British Columbia	Dr. R. Knight	372,000	The Use of Radar Methods to Determine Moisture Content in the Vadose Zone	To focus on two specific aspects of the link between radar images and moisture content. The research will improve the usefulness of radar as a means of characterizing moisture content in the vadose zone.
Sandia National Laboratories	Dr. G. Newman	656,000	High Frequency Electromagnetic Impedance Imaging for Vadose Zone and Groundwater Characterization	To address the use of magnetotelluric inversion codes to interpret data and limiting factors of 2D and 3D inversion schemes. Results will help DOE develop better ways to characterize the subsurface and thereby predict contaminant transport in the vadose zone.
Ohio State University	Dr. S. J. Traina	1,139,000	Immobilization of Radionuclides in the Hanford Vadose Zone by Incorporation in Solid Phases	To address how, and under what conditions, soluble Cs, Co, Sr, Tc, and U in SST leachates are attenuated in the vadose zone, adsorption and precipitation reactions. This information will have direct impact on the development of geochemical transport models and on remediation strategies that deal with vadose-zone contaminants in High-Level Waste tank plume environments.
Oak Ridge National Laboratory	Dr. P. M. Jardine	1,210,000	Fate and Transport of Radionuclides Beneath the Hanford Tank-Farms: Unraveling Coupled Geochemical and Hydrological processes in the Vadose Zone	To provide an understanding and predictive capability of coupled hydrological and geochemical mechanisms that may be responsible for the enhanced migration of radionuclides in the vadose zone at the Hanford site. Unsaturated flow and transport experiments, combined with multiple tracer strategies and novel surface analyses, will provide knowledge in previously unexplored areas of vadose zone contaminant transport.

<b>Institution</b>	<b>Investigator</b>	<b>\$ Award</b>	<b>Title</b>	<b>Summary</b>
New England Research, Incorporated	Dr. S. R. Brown	570,000	Complex Electrical Resistivity for Monitoring DNAPL Contamination	To develop a new methodology for field measurement of complex resistivity for characterization and monitoring of DNAPLs. The resistivity measurements will be an effective tool for monitoring the progress of remediation activities.
PNNL	Dr. F. J. Brockman	1,050,000	Integrated Field, Laboratory, and Modeling Studies to Determine the Effects of Linked Microbial and Physical Spatial Heterogeneity on Engineered Vadose Zone Bioremediation	To evaluate an approach for removal of carbon tetrachloride from the vadose zone using enhanced biodegradation via gas-phase nutrient injection. Results will be used to improve the accuracy of current models that predict microbial attenuation of contaminant transport in the vadose zone.
PNNL	Dr. P. D. Meyer	600,000	Quantifying Vadose Zone Flow and Transport Uncertainties Using a Unified, Hierarchical Approach	To develop and demonstrate a general approach for modeling flow and transport in a heterogeneous vadose zone. The approach will use geostatistical analysis, media scaling, and conditional simulation to estimate soil hydraulic parameters at unsampled locations from field-measured water content data and a set of scale-mean hydraulic parameters. Results will help to elucidate relationships between the quantity and spatial extent of this characterization data and the accuracy and uncertainty of flow and transport predictions.
PNNL	Dr. C. J. Murray	850,000	Influence of Clastic Dikes on Vertical Migration of Contaminants in the Vadose Zone at Hanford	To investigate the possibility that clastic dikes provide preferential pathways that enhance the vertical movement of moisture and contaminants through the vadose zone. New characterization techniques to be demonstrated in the project could be applied across the Hanford Site, as well as at other sites where vertical faults influence the contaminant transport through sediments.
Washington State University	Dr. M. Flury	700,000	Colloid-Facilitated Transport of Radionuclides Through the Vadose Zone	To study formation and mobilization of colloids, association of contaminants with colloidal particles, and co-transport of colloids and contaminants in the vadose zone. Results will lead to improved conceptual models of colloid-facilitated transport at the Hanford site.
University of Wisconsin - Madison	Dr. D. Alumbaugh	1,005,000	A Hydrologic-Geophysical Method for Characterizing Flow and Transport Processes within the Vadose Zone	To analyze flow within a mid-scale hydrologic test to determine the amount of transport within the vadose zone. This project will employ numerical and experimental tools being developed under a previously funded EMSP proposal. Results will help to better understand flow and transport modes within the vadose zone at DOE sites, including the influence of natural heterogeneities and man-made structures.
University of Wyoming	Dr. J. Bradford	648,000	Material property Estimation for Direct Detection of DNAPL using Integrated Ground-Penetrating Radar Velocity, Imaging, and Attribute Analysis	To develop a suite of methodologies for direct detection of pooled and residual DNAPLs from surface GPR data. This unique approach to the analysis of GPR data will determine material properties remotely by quantifying signal characteristics such as propagation velocity and waveform attributes such as amplitude, frequency content, and phase. This effort, if successful, will reduce the cost of DNAPL remediation.

There are three types of transport experiments that will be conducted at the test sites. These include tests using:

1. Dilute aqueous tracers, in relatively uniform, well-characterized sediments
2. Concentrated aqueous tracers in relatively uniform, well-characterized sediments and,
3. Concentrated aqueous tracers in sediments containing fractures, clastic dikes, or other extreme physical features that might accelerate or hinder rapid transport, thereby leading to flow non-uniformities.

### **3.0 OBJECTIVES**

A key issue to be addressed by the VZTFS is the identification of mechanisms contributing to accelerated flow and transport in the subsurface at Hanford. Non-uniform flow can be caused by both chemical and physical mechanisms and often results in accelerated transport of contaminants through the subsurface. Other important issues include the impact of waste chemistry on temporal variations in hydrologic properties of vadose zone sediments and the impact of spatial and temporal heterogeneities on contaminant migration rates and distributions. Based on these key issues, there are four main objectives to the Vadose Zone Transport Field Study. These objectives are:

1. to develop accurate conceptual models based on the detailed assessment of fluid flow and chemical transport in Hanford sediments under conditions representative of high-level waste tank farms and past-practice disposal facilities,
2. to obtain data capable of providing a test of the predictive capability of vadose zone transport models,
3. to evaluate techniques and instruments that will assist in the cost effective and timely characterization of sites at Hanford, and
4. to elucidate the mechanisms controlling the migration of contaminant plumes within the Hanford vadose zone in the region of tank farms and ancillary waste sites.

The core projects at the Hanford site, including those dealing with characterization of the high-level waste tank farms and the solid waste burial sites will benefit from the VZTFS program both by the evaluation and application of the advanced characterization methods and the data sets that will be useful for improved model assessment of contaminant plumes.

Experts in vadose zone geohydrology, geochemistry and geophysics from PNNL, INEEL, LANL, LBNL and from academic and private institutions will work together to plan and implement appropriate field experiments toward meeting these objectives. Vadose zone transport theory and conceptual models developed from these studies will be applicable to groundwater contamination problems associated with tank farms and other past practice disposal sites as well as planned disposal facilities such as the Immobilized Low Activity Waste (ILAW) facility. The studies will also provide data sets for transport model verification useful in supporting the System Assessment Capability (SAC) effort and other performance assessment activities required for future waste disposal at the Hanford Site.

## 4.0 PLANNING OF RESEARCH

To, plan, coordinate and direct the research in the Vadose Zone Transport Field Study, a Multi-Laboratory-User Steering Group has been established. The Steering Group is comprised of EMSP Principal Investigators from the National Laboratories; Site User representatives; the System Assessment Capability (SAC) Project; the Immobilized Low-Activity Waste (ILAW) Project and the 200 Areas Soil Sites. The Steering Group currently consists of the following individuals:

### **Hanford Site Coordinators**

<sup>1</sup>Glendon Gee –PNNL (Lead)

<sup>1</sup>Anderson Ward—PNNL (Co-Lead)

### **Hanford Site User Representatives**

Tony Knepp- FDH (RPP, Tank Farm Characterization)

Fred Mann (ILAW)

George Last- PNNL (SAC)

Bruce Ford- BHI (200 Area Sites)

Vern Johnson-PNNL (RCRA GW)

Rob Yasek- DOE-RL (RPP Rep)

David Olson-DOE-RL (GW Rep)

Jim Hanson-DOE-RL (S&T Lead)

### **National Laboratory Representatives**

<sup>1</sup>Everett Springer- LANL

<sup>1</sup>Don DePaolo- LBNL (also Vadose Zone Transport Model Representative)

<sup>1</sup>JB Sisson- INEEL

Ken Jackson-LLNL

John Zachara-PNNL (Vadose Zone Representative Sites Interface)

### **EMSP Representatives**

Phil Meyer-- Project 70149 (PNNL)

Phil Jardine-- Project 70219 (ORNL)

Charles Carrigan--Project 70149 (LLNL)

Chris Murray-- Project 70193 (PNNL)

Greg Newman—Project 70220 (SNL)

A number of EMSP projects have been awarded for FY 2000 that could have application to the Vadose Zone Transport Field Study (VZTFS). Table 1 lists funded projects where potential contributions or collaboration efforts could enhance the development of one or more tests under direction of the VZTFS. To expedite the planning activities, the executive committee will meet periodically through phone conferencing and site visits. The entire steering committee is expected to meet at least annually and will review the overall plan and provide comment on the specific test

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<sup>1</sup> Executive committee charged with drafting research plans.

plans as they are developed. In addition to the steering committee, this project will be reviewed by the Hanford Vadose Zone Expert Panel, and a National Academy of Sciences Review Panel.

#### *Workshops*

The planning process will be expedited by two workshops. The first workshop, completed in November, 1999 involved all of the award winners for the FY 2000 EMSP call for research proposals related to Hanford vadose zone issues. An *Advanced Vadose Zone Characterization* workshop will be held in January 19-20, 2000. Members of the steering group will participate in the January workshop.

#### *Initial Milestones*

A focused approach centered on key issues of vadose zone flow and transport at Hanford will be used in the research investigations at selected sites. Data and analysis from the field studies will be incorporated into the System Assessment Capability's (SAC) Rev.1 analysis, which requires data input by August 2001. The thrust of this effort will be to provide support to estimate vadose-zone travel times for contaminants such as technetium-99, iodine-129, and nitrate using conservative (i.e. non-reactive) surrogates such as chloride and bromide under conditions that are typical of tank farms and specific retention basins at the Hanford Site. The studies will also support the River Protection Project (RPP) that will require input for the B-BX-BY Tank Farm Field Report by Oct. 2001.

## **5.0 SITE SELECTION**

The present study is intended to investigate glacial-fluvial deposits at the Hanford Site that are representative of those that may or already have caused vadose zone or groundwater contamination. Selection of sites for vadose zone transport testing will be based on their relevance in addressing specific flow and transport problems at Hanford. The selection process will consider the degree to which they have been previously characterized; the nature and extent of their heterogeneities; their similarity to actual waste sites of interest; and their ease of access. Cost for infrastructure, including excavation permits, power and water accessibility, etc. also will be factored into the selection process.

The scale of observation is another important issue. There are essentially four mechanisms of preferential flow and their relative importance depends on the scale of observation. Macropore flow/channeling occurs in networks of holes or fractures with apertures of 1 mm or more. In mesopore channeling, water and contaminants move through networks with apertures less than 1 mm. A third type, fingered flow, is not normally associated with physically defined channels but is caused by wetting front instability and changes in the water retention function such as those that cause water repellency. The fourth, which occurs at a much larger scale, is often referred to as funnel flow and results from profile heterogeneity. Low permeability layers or coarse lenses in a profile may restrict vertical movement, redirecting flow laterally through localized regions of the profile. The selected site should be one that facilitates observation of these processes.

It is also widely known that observations made at one scale are not easily extended to larger scales. Field observations also suggest that the effect of the underlying spatial variability on flow

may change as the size of the flow field increases. Consequently, it will be necessary to observe flow and transport at length scales comparable to the total transport distance in WMAs in order to derive parameters that can be used to verify transport-modeling predictions. In order to get an appreciation for the necessary scales a brief review of the WMAs of interest is presented below:

The single shell tanks (SSTs) at Hanford are generally 22.8 meters in diameter and 13.5 meters tall. Tank installation involved a single large excavation to a depth of about 16 meters, after which the bottom grade for the tanks was established. The material was compacted before the concrete bases of the tanks were poured and after the tanks were built, the original excavated material was backfilled around the tanks. The tanks were covered with about 2 meters of backfill material. Figure 1 shows an example of such an excavation.



**Figure 1.** Photograph of Hanford's Underground Tanks as they were being constructed. The depth to the base is approximately 16 m. (A study of flow and transport processes relevant to tank farms and past practice disposal areas will need to interrogate the regions of the vadose zone that controls waste migration).

Other waste facilities in the vicinity of the tank farms include cribs, French drains, and trenches. The dimensions of cribs near the SSTs were usually 4 m long by 4 m wide by 3 m deep, putting their base just at the top of upper Hanford Formation. French drains were typically gravel-filled trenches 3 m long, 3 m wide, and about 2 m deep. Trenches varied in length from 3 m to 175 m, with widths varying from 3 m to 20 m, and depths varying from 3 m to 8 m.

A potential site for the first set of field tests is in the 200 East Area. The site, which has a relatively uniform lithology, is the site used by Sisson and Lu (1984) for a field injection experiment; located just east of the proposed site for construction of the ILAW disposal facility

The Sisson and Lu injection site includes a well system consisting of an injection well surrounded by forty two 15-cm diameter observation wells that extend to a depth of about 18 m. Directly to the east of the Sisson and Lu injection site is the 216-A-38 crib, a crib reported to have never been used. The area to the west of the injection site was used in experiments to characterize the Hanford Surface Sediments and the Upper Hanford Formation in support of the Hanford ILAW Performance Assessment. As part of the site characterization activities for the ILAW disposal facility, sediment samples were obtained via a borehole and sampling program from the area southwest of the injection site. A total of 45 undisturbed cores were obtained from the borehole (299-E17-21) which extended down to 146 m; the water table was at 100 m. Twenty cores were analyzed to determine particle size distributions and the  $\psi(\theta)$  functions. To the east of borehole 299-E17-21 is the long-term plume migration field site at which the vadose zone transport of high salinity fluids is being investigated under an FY 1998 EMSP Award. This research is focussed on the effects of wetted path geometry, salinity gradients and vapor flux on the migration of highly saline wastes.

The Sisson and Lu site is a potentially good location for the first set of VZTFS experiments. It is close to a power supply and offers easy access. It is not considered to be ecologically sensitive and has been relatively well characterized. The site is large enough to potentially allow excavation of a trench to expose the Upper Hanford Formation, the soil unit of interest in these studies.

## **6.0 GENERAL RESEARCH PLAN**

### **6.1 Hypothesis Testing**

The movement of water and chemicals through the vadose zone requires knowledge of the four state variables water content,  $\theta$ , water potential,  $\psi$ , chemical concentration(s), and temperature. The goal of vadose zone modeling is to generate numerical values of the state variables throughout the subsurface given changes in boundary conditions and/or source terms. Typically the models used are Richard's equation for water movement, Fourier's Law for heat conduction and the convection-dispersion equation for the transport of chemicals. These equations are commonly referred to as the transport equations and are based on conservation of mass and energy.

The main assumption underlying modeling contaminant transport throughout the vadose zone is that the transport equations adequately describe transport throughout the subsurface. This assumption can be restated as all processes that govern transport in the vadose zone are encompassed in the transport equations. If the vadose zone were made up of materials that were uniform this assumption could be evaluated from a spatially sparse array of sensors. Since the vadose zone is made up of a composite of materials with rapidly varying hydraulic properties the hypothesis is not directly testable. The effort required to accurately characterize a site with respect to hydraulic properties is impossible at this time using the currently available destructive methods.

Each of the models requires parameters, usually in the form of mathematical functions that allow changes in the state variables to be quantified throughout the vadose zone. An assumption underlying transport modeling is that as the spatial grid size decreases the model values output by the model approaches their “true values”. Since the vadose zone is composed of materials that vary widely over small distances, estimates of the transport parameters must be available at small spatial scales for the numerical models to converge to the “true values”. Due to the spatial variation in transport properties and the inability to “see” through the vadose zone and collect spatially dense sets of data, the basic assumption cannot be tested directly. A further barrier to testing the basic assumption in the field is that the computational demands of using smaller and smaller grids exceed existing computer capacity.

While the basic assumption is not directly testable it is possible to form other hypothesis's that may be testable. Among the other hypotheses that could be testable include:

1. The standard hypothesis where the vadose zone is divided into grid blocks to provide a numerically tractable solution,
2. The sparse grid hypothesis where the transport properties of large volume blocks are estimated by building up the block from transport properties obtained at a finer scale,
3. The transfer function hypothesis where transfer functions are used in place of the actual transport equations.

The three hypotheses have not been tested at scales applicable to field problems. The lack of tests has stemmed from a lack of instruments and methods needed to perform the basic field experiments. The needed instruments will be capable of monitoring water content, water potential and chemical concentrations throughout large volumes of vadose zone materials. The field-tested instruments available today include the borehole water-content sensors (BWCS) and the Advanced Tensiometers (AT) developed recently at the INEEL. These instruments are capable of monitoring in real time water contents and water potentials at points in the vadose zone (see for example the data displayed at URL <http://etd.pnl.gov:2080/vadose/>--Vadose Zone Transport Field Studies: Advanced Tensiometers). Vacuum lysimeters have been commercially available for a number of years and are suitable for obtaining soil solution samples for laboratory analysis. Recent advances in fiber optic sensors for specific chemical species make monitoring of contaminants in the shallow subsurface possible. Temperature thermocouple, thermistor, diode, infrared, etc.) sensors have been available for decades and provide measurement possibilities for documenting non-isothermal processes. But these sensors and samplers obtain values at points and do not average over large volumes. Geophysical methods will be required to obtain estimates of the state variables between boreholes and for estimating large volume averages of the state variables. The geophysical methods available include cross borehole ground penetrating radar and electrical resistance tomography. To cover a test site adequately, the geophysical methods may take several hours each to obtain data for a snapshot in time and considerable time may be required to invert the data sets to obtain estimates usable in the larger study. Thus, the geophysical data will be available at sparse time intervals but at a high spatial density, whereas the data from the point sensors will be available nearly continuously in time but will be spatially sparse.

By combining the geophysical and point measurements, the 3 hypotheses can be evaluated and tested in the same transport volume using the same set of experiments.

## 6.2 Approach and Expected Results

A phased approach will be used for the field tests. Phase 1 will focus on characterization of initial conditions of the chosen site and determination of hydraulic parameters. Parameters will be derived from existing data where possible, from the analysis of disturbed and undisturbed soil samples, and from field measurements. Phase 1 should provide insight into the variability of hydraulic parameters, including anisotropy in  $K_{sat}$ . Background characterization of the VZTFS sites will provide data for initial modeling and assist in the design of subsequent field tests. Data to be collected include hydraulic properties, information on stratigraphy, and chemical information. Some laboratory studies to determine the chemical interaction of the tracers may be needed.

Phase 2 will focus on process characterization and will include assessment of the physical and chemical properties affecting the vadose zone transport processes. Phase 2 will occur during and after the actual transport tests. Larger scale hydraulic tests will be performed at or near the sites used for the initial characterization to provide data for a larger scale. The needs for these tests will be established as part of the detailed test plan effort.

State variables (water content, pressure, temperature, time, and concentrations) will be monitored wherever possible. The tests will focus on the flow of water and chemicals in the subsurface sediments through areas of at least 10 m in extent. The rationale for large-scale field-testing is to capture the effects of sediment heterogeneities on transport. Upscaling of data collected from small core samples for hydraulic characterization will be used initially, in an attempt to describe field-scale transport. However, it is clearly recognized that the primary hydrologic data will be from *in situ* measurements. As testing proceeds, conditional simulations, based on variations in initial water content or pressure profile data to describe the variation in hydraulic properties, will be used in a three-dimensional model to compare estimated and measured transport. Inverse modeling, in which modeling parameters are conditioned on the experimental results, may also be used to obtain hydrologic and geochemical characteristics of the test area.

Models will be used to assess vadose zone transport at Hanford for various risk scenarios. The VZTFS will provide the opportunity to test models under controlled conditions to determine prediction capabilities and/or provide an estimate of the uncertainty in model predictions. Model predictions will use a set of prior information to predict the state variables, with or without uncertainty, which can be evaluated against the field test as it proceeds. This will require integration between the Transport Modeling and the VZTFS tasks in order to improve our prediction capabilities or better estimate the uncertainties. The VZTFS experiments offer the opportunity to enhance our modeling capabilities of vadose zone transport at Hanford and understand sources and magnitudes of uncertainty.

## 6.3 Characterization and Monitoring

It is anticipated that the field tests will utilize the best available characterization and monitoring tools available for the vadose zone. A precursor to Phase 1 will be the review and selection of advanced characterization and monitoring tools. Hydrologic characterization tools include disk permeameters for measurement of unsaturated hydraulic conductivity and tensiometers and heat dissipation units for measurement of in situ capillary pressures (matric potentials). Geophysical tools of interest include: gamma attenuation (for formation density determinations); electromagnetic induction [EMI] (for electrical conductivity and water content profiling); neutron scattering (for water content profiling); surface-deployed ground penetrating radar (for water content and layer discrimination); electrical resistance tomography [ERT] (for profiling of bulk electrical conductivity); and time domain reflectometry [TDR] (for water content and electrical conductivity profiling). In addition, some of the newer tools and techniques that will be reviewed for applicability include cross-borehole ground penetrating radar; and cross-borehole seismic tomography, which can provide high resolution images of profile heterogeneities without the limitations of traditional surface seismic surveys.

Most of the tools developed for monitoring state variables in the vadose zone were developed for near surface use. However, recent innovations have produced tools capable of deep vadose zone monitoring. Recent innovations capable of monitoring state variables include: advanced tensiometers, for profiling matric potential; surface nuclear magnetic resonance (NMR), with the potential to measure water content as well as pore size distribution, which is related to the water retention function; and through-casing electrical resistance tomography (TCERT), capable of using existing steel-cased wells as electrodes for measuring electrical conductivity profiles.

## 6.4 Potential Test Activities

Carefully planned tracer tests will be the central part of this project. Injection and manipulation experiments will be planned and initiated. A series of tests will be planned for implementation over the next three years, with the first test implemented in April 2000. The tests will use both conservative and reactive tracers.

Over the course of a four-year effort, three types of tracer tests will be conducted. These include tracer tests using:

- 1) dilute fluids, in relatively uniform, well-characterized sediments,
- 2) concentrated fluids, in relatively uniform, well-characterized sediments,
- 3) concentrated fluids in sediments containing clastic dikes (or other extreme features) that might either accelerate or hinder rapid transport in the vadose zone at Hanford waste sites.

Tracer tests using dilute fluids will be run initially at one of the VZTFS sites. An area of more than 100 m<sup>2</sup> will be tested at water infiltration rates less than saturation. The site will be initially characterized for its hydrologic variability using disk permeameters for measurements of variations in unsaturated hydraulic conductivity and neutron logging or reflectometry for water content variations. A variety of constant flux application methods will be evaluated. The data from these tests will be used to provide *in situ* characterization of the hydraulic properties and quantify the spatial variability of the test facility. For the tests that are designed to simulate tank leaks, a concentrated solution of sodium nitrate will be used. Concentrations of 5 mol kg<sup>-1</sup> will

emulate the density and viscosity of tank waste solutions without the high levels of radioactivity. Field tests aimed at determining the effects of clastic dikes will be performed at sites where such features have been characterized, such as at the Environmental Restoration Disposal Facility (ERDF).

Additions of isotopic tracers will be considered and may include, labeled Sr, U, Ca, Pb, C, N, Mo, Eu, Te. A number of other isotopic tracers could be used depending on specific goals of the tracer tests. Pore water samples will be collected and analyzed for conservative and reactive species where feasible. For the tank-leak related tests, experiments will include the placement of a simulated tank within the test area and monitoring of leakage from the tank and subsequent water fluxes from accelerated water input from the surface. The surface condition will be controlled so that surface-ponding will not be allowed (only unsaturated flow) to simulate meteoric water infiltration rates. Pulses of water will be released in a fashion that mimics the winter snowmelt events at Hanford. Monitoring of the water and solute fluxes under the specified boundary conditions will be the focus of the testing. Distributions of water and chemicals over time will be documented and used in model comparisons in concert with the Transport Modeling Task of the overall Vadose Zone Project. Details of three test efforts will be provided as the plan is further developed.

It is anticipated that the Advanced Characterization workshop to be held in January 2000 will be helpful in identifying the most promising technologies currently in place for conduction the Hanford vadose zone transport experiments. It is anticipated that the discussions and presentations at the workshop will be helpful in selecting methods that can be used in the Hanford environment so that the experiments can be both meaningful and cost effective.

## **7.0 SCHEDULE AND MILESTONES**

### **FY 2000**

Nov. Present Broad Test Plan to Steering Group at EMSP-2000 S&T Workshop.

Jan. Conduct Workshop on Advanced Characterization Tools

Apr. Prepare Detailed Test Plan for Field Work

May. Begin First Tracer Test at selected VZTFS-Simulated Tank Site

Sept. Analyze Data from VZTFS

Sept. Prepare Detailed FY01 Test Plan

### **FY 2001**

Oct. Participate in Second Field Test Workshop

Nov. Finalize Second Tracer Test Plan

Jan. Select Advanced Characterization Tools

Feb. Begin Second Tracer Test-Simulated Tank Site

Aug. Prepare Leak Simulation Report

Sept. Prepare Detailed FY 02 Test Plan

FY 2002

Oct. Participate in Third Field Test Workshop

Nov. Finalize Deep Sediment Tracer Test

Feb. Begin Deep Sediment Tracer Test

Aug. Prepare Deep Sediment Transport Report

Sept. Prepare Detailed FY 03 Test Plan

FY 2003

Oct. Participate in Fourth Field Test Workshop

Nov. Finalize Second Deep Sediment Tracer Test

Feb. Begin Second Deep Sediment Tracer Test

Aug. Prepare Second Deep Sediment Transport Report

Sept. Finalize Data Sets for Modeling of VZTFS experiments